NEUTRALIZATION EFFICIENCY OF PLASMA TARGETS FOR HIGH ENERGY
NEGATIVE IONS*

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ABSTRACT

Plasma targets generated by hollow cathode discharges are used to neutralize a variety of multi-MeV negative ions as heavy as 28 a.m.u. Our plan is to determine the neutralization efficiency of hydrogen and argon plasma targets for D^- , Li^- , C^- , O^- , and Si^- at beam energies of 2-8 MeV. The experiment is still in progress. Encouraging initial results are reported.

INTRODUCTION

Tokamak and mirror fusion reactors will require some method of auxiliary heating. In addition, tokamaks will need a noninductive method for current drive, while TMX devices require maintenance of a potential barrier at the end plugs. For heating, deuterium beams with energies in the hundreds of KeV will be required for these reactors, while for current drive or mirror plugging, the deuterium beams need energies of about 1 MeV. As an alternative to the use of deuterium beams for auxiliary heating, mirror plugging and current drive, neutral beams of heavier atoms such as O^0 with energies of about 1 MeV/nucleon have been proposed.¹

At present, experiments, designed to determine the neutralization efficiency by argon and hydrogen plasma targets of multi-MeV D^- , Li^- , C^- , O^- , and Si^- are in progress at the Brookhaven National Laboratory Tandem Van de Graaff Facility. These experiments are similar to a previous study² in which the neutralization efficiency of a differentially pumped gas cell was measured for Li^- , C^- , O^- , and Si^- at 2-7 MeV with target gases of N_2 , CO_2 , and Ar.

Neutral and charged particle fractions produced by passing negative ion beams through plasma targets have been measured. From this data neutralization efficiencies have been computed. Since no sufficient data for the interaction of these multi-MeV ions with plasma ions and electrons exists, it was impossible to design the best plasma neutralizer. Therefore, a plasma neutralizer suitable for 200-500 KeV H^-/D^- beams has been used. The plasma neutralization utilizes plasmas injected from hollow cathode discharges.

EXPERIMENTAL ARRANGEMENT

The negative ions were produced and accelerated by the Tandem Van de Graaff Accelerator Facility at Brookhaven National Laboratory. Figure 1 shows the beam line which has been used to make

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MASTER

Fig. 1. Diagram of the experimental arrangement

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the measurements. In this beam line, the foredeflectors which are located 5 m ahead of the entrance to the neutralizer are used to deflect the negative ions through 2° to purify the beam of other charge states which are formed during transport. This geometry prevented the achievement of maximum neutralization efficiencies due to some formation of other charge states before the beam entered the neutralizer. At a distance of 20 cm downstream from the neutralizer exit, postdeflector plates separate the resultant charge states. A surface-barrier particle detector is translated across the end of the beam line to measure the final charge-state distribution.

Figure 2 is a more detailed diagram of the plasma neutralizer, which is fed by two hollow cathode discharges. The arrangement is similar to a configuration³ which was used to estimate the power efficiency of plasma targets produced by hollow cathode discharges. But unlike that previous scaled-down version, this neutralizer has a plasma target which is 1 m long, and it is differentially pumped. The plasma is injected from two hollow cathodes through collimators into the main chamber at 30° to the plasma target axis where the plasma is confined by a solenoidal magnetic field of about 200 Gauss. During the experiments, additional partitions with apertures were added on both sides of the neutralizer to reduce the gas pressure in the rest of the beam line. Thus, the neutralizer target is differentially pumped from the small chambers which house the cathodes, and the beam line is differentially pumped from the plasma target.

Fig. 2. Schematic of the plasma neutralizer.

RESULTS

In the previous study,² maximum neutral yields for gas neutralizers were determined to be 42, 27, 21, and 22% for Li^- , C^- , O^- , and Si^- , respectively, with little or no dependence on either beam

energy (2-7 MeV) or target gas (N_2 , CO_2 , Ar). For the present study, the maximum neutral yields for Li^- at 3 MeV using an H_2 gas target were determined to be 50%. Under not yet optimal conditions, the hydrogen plasma target produced a higher neutral yield of 56%. The corresponding charge-state spectra are shown in Figures 3 and 4. Table I summarizes the preliminary results.

At this time, the plasma parameters have not been measured. Since the plasma density, i.e., target thickness, depends on the arc current, gas pressure, magnetic field strength, etc., the charge-state composition of the beam emerging from the neutralizer has been measured as a function of the arc current, while all other parameters were kept constant in each set of measurements. For plasma densities of interest to this subject matter, the plasma density in

Fig. 3. Charge state spectra of Li^- at 3 MeV after passing through a hydrogen-gas neutralizer.

a hollow cathode discharge is proportional to the arc current. Furthermore, for plasma densities of 10^{12} - 10^{13} cm^{-3} the dependence is linear.³

Our goal is to systematically study the neutralization efficiency of this type of plasma target to determine its maximum capabilities. This is not presently possible. We plan to modify the apparatus to allow for higher solenoidal magnetic fields, a shorter flight path between the foredeflector and the entrance to the neutralizer, and diagnostic probes to determine the plasma profile

Fig. 4. Charge state spectra of Li^- at 3 MeV after passing through a hydrogen plasma neutralizer.

along the length of the target. These improvements will enable us to reach higher plasma densities, minimize charge changing before the target, and ensure maximum overlap between the ion beam and densest part of the plasma. It will then be possible to make systematic measurements of neutralization versus plasma density and to ultimately optimize the performance of this type of plasma neutralizer.

Table I. Preliminary results using 3-MeV negative ions

Projectile	Neutralizer	maximum Neutral Fraction
Si ⁻	Ar plasma*	27%
C ⁻	Ar plasma*	35%
C ⁻	H ₂ plasma	43%
Li ⁻	H ₂ gas	50%
Li ⁻	H ₂ plasma	56%

*with no differential pumping between target cell and beam line.

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